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FOREIGN TECHNOLOGY DIVISION

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by

Witold Gutowski

EDITED TRANSLATION

FTD-ID(RS)T-0342-78 13 April 1978

MICROFICHE NR: FTD-78-C-000528

CSI77270490

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English pages: 19

Source: Inzynieria Chemiczna, Vol. 7, No. 2, 1977, pp. 341-354.

Country of origin: Poland
Translated by: SCITRAN
F33657-76-D-0390
Requester: PHE

Attachment Criterion of the Diffuse Phase Particles in the Dispersive System, to the collision surface in the quasi-elastic Rebound and Rolling Cases.

by

Witold Gutowski

Abstract:

A stable attachment or separation criterion has been determined for the particle of a diffuse phase in flowing aerosol or hydrosol in the case of the effect of its quasi-elastic rebound after a streamlined obstacle collision. This criterion is analogous to the one derived previously on the assumption of particle sliding dislocation on the surface collision caused by fluid viscosity drag force. The new criterion differs from the previous one in that there is no friction coefficient present in it, but a collision angle instead.

1. Introduction

In the work (1) the criterion was introduced, for the particles attachment (or separation) to the surface streamlined by the dispersive system (aerosol or hydrosol). The collisions between particles and the streamlined surface are due to various mechanisms like for example, diffusion in the case of small (Brownian) particles and velocities, inertial deflection from the stream in the case of heavier particles or higher velocity, adhesion of the particles sufficiently close to the surface, gravitational or electrostatic deflection from the stream (in the case of external electrical field). The streamlined surface than plays the role of separator between the dispersed and dispersing phase. The particle will be separarted if it collides with the mentioned surface and if the achesion force is greater than the reaction force. It is more convenient to use the energies instead of the forces. The adhesion energy is obtained by multiplying both sides of the Deryagin equality by the displacement corresponding to the state of particle separation (1.).

Such a state exists for the particle moving along the surface, and for the separation in the direction normal to this surface, the displacement corresponds to the distance at which one can ignore the adhesion forces (molecular, electrostatic). Therefore, for the criterion, the following ratio is used (1.):

$$a_p^* = \frac{E_p}{E_r}, \qquad (1)$$

where E_p - adhesion energy, E_r - reaction energy. In this case the "inelastic" case was considered, ie. the separation due only to the translational motion of the particle along the surface caused by the fluid viscosity. In this case $E_p = \mu_o E_A$, where μ_o is the staic friction coefficient between the particle and the surface, and E_A is the adhesion energy, equal to the product AS_r, where A is the adhesion energy on the unit of the contact surface (specific adhesion energy), S_r - the actual contact surface (particle contact with the colliding surface). It was further assumed that $S_r = \xi_o S_k$, where ξ_o is the contact coefficient ($\xi_o < 1$), and S_k - the kinetic (envelope) particle surface . The linear measure of this surface is (2) the kinetic particle dimension $a_k = (S_k / \psi_s)^{1/2}$, where ψ_s is the equivalent shape coefficient of the particle kinetic surface. Furthermore, the fluid gives the particle the energy $E_r = mu_p^2 / 2$, where m is the particle mass, u_p the mean particle velocity at the distance a_k from the surface along which the particle travels. The mass of the porous particle can be expressed by (2) : $m = \rho_f V_f$, where ρ_f is the density, V_f - the particle volume (excluding the pores, except the closed pores included in ρ_f), which linear measure is the static volume size, equal $a_v = (V_f / \psi_v)^{1/3}$, where ψ_v is the coefficient of equivalent particle volume V_f.

According to the author's latest studies (2), the relations between the quantities a_v , a_k and the dynamic quantity a are as follows

$$a_k = a[f/(1-\beta_c)]^{1/2} \quad \text{and} \quad a_v = af^{1/2}/(1-\beta_c)^{1/6},$$

where β_c denotes the particle porosity.

In these formulas the so called kinetic shape coefficient, χ_o used in (1), was ommited, which is approximately equal to 1 for not too elongated or disc-like particles, and f is the motion coefficient. The transition from the geometrical quantities a_v, a_k) to the dynamic one, is justified on the fact that the determination methods for this quantity and the particle distribution v.s. the dynamic quantity, known also as the sedimentational , are best known and widely used; and the approximate method for determination of β_c, as the mean porosity of the particle set, is presently being developed (2).

Taking into account the given relations, and the fact that $\psi_s/\psi_v = 6$ (for the effective sphere, hexagon, or cylinder with the diameter equal to the height) one obtains from the equation (1):

$$G_\mu^* = \psi_0 \frac{A}{a u_p^2 \varrho_f \sqrt{1-\beta_c}}, \qquad (2)$$

where $\psi_0 = 12\mu_0\xi_0/\sqrt{f}$. The quantities μ_0 and ξ_0 are unknown (in fact undeterminable), therefore, ψ_0 needs to be treated as the empirical constant. The quantity f for the non elongated or non disc particles is on the average 0.963 (2).

Considering the phenomenon in the fluid boundary layer at the colliding surface, the nonstatic layer and the stream mixing phenomenon in the streamlined system, the expression was obtained determining the criterion G_p^* in the cases of laminar and turbulent flows. For the problem considered here, the form of G_p^* for the second case is of

interest, and is given by

$$C_p^* = \nu_p'' \frac{A}{au^2 \varrho_1 \sqrt{1-\beta_0}}, \qquad (3)$$

where u is the fluid velocity near the streamlined elements and

$$\nu_p'' = 12\mu_0 \xi_0 / c_0^2 \sqrt{\beta};$$

C_0 is the constant resulting from the assumption $u_p = C_\theta u$ (1). The velocity u is determined (3,4) by

$$u = \frac{u_0}{2H^*}, \qquad (4)$$

where H^* is the hydrodynamic coefficient, obtained from the velocity fluid equation for the flow around the object, and u_0 the velocity far away from the object. For example, for the system of high porosity fibers ($\beta_k > 0.9$) the hydrodynamic coefficient of Happel - Kuwabara is used (3)

$$H^* = -0{,}5 \ln\beta + \beta - 0{,}25\beta^2 - C, \qquad (5)$$

where $\beta = 1-\beta_k$ is the so called system packing degree, the the constant C is equal to 0.5 according to Happel and 0.75 according to Kuwabara. For the flow around the cylinder at the low Reynolds number ($Re < 0.5$) the Lamb hydrodynamic coefficient $H^* = 2.002 - \ln Re$ is used (3.4.5).

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The liquid flow velocity in the porous system can be replaced by the measurable inflow velocity w, which is the ratio of the volume flow intensity to the perpendicular cross section surface.

$$u_0 = \frac{w}{\beta_0}. \tag{6}$$

The criterion (3) after the substitution of the hydrodynamic factor will become

$$Ar_{kr}^{\circ} = 4Re^{*2}\psi_p'' - \frac{A}{au_0^2\varrho_f\sqrt{1-\beta_c}}. \tag{7}$$

The particle moving along the surface can be separated because the boundary layer separetes or because of its instability due to the turbulences along the surface or at the edges or sharp corners.

The latest studies (6,7) show, that in the case of particle adhesion to the thin fibers, the adhesion forces are so strong that the particle separation cannot be attributed to the motion or tubulence of gas, Accordingly, the authors (6) introduced the hypothesis of the elastic particle rebound. The adhesion (or separation) criterion for this case, which is not limited to fibers, is the goal of this work. In addition, the case will be considered in which the particle rolls along the colliding surface.

In the models used for the derivation of the adhesion criterion, both in (1) and in this work, the surface deformation at this collision was ignored. Inclusion of those deformations would increase the value of the contact coefficient. The contact coefficient ξ_0 would increase and the particle energy at the collision (ie. the reaction energy) would decrease. This problem of the influence of deformation on the particle adhesion was studied in (8), in order to explain the increase in the number of trapped particles above certain velocity, called the second

critical velocity.

In the work (6) the expression for the particle energy in the collision with deformation was derived, and the expression for the penetration depth for the spherical particle. This penetration would cause the increase of the contact surface, thus the increase in the contact coefficient. Undoubtedly, the value of this coefficient would depend on the particle type and the colliding surface, to a much greater degree than for the plastic deformation. The exchanged energy corresponding to the reaction energy is (8)

$$W_r = m^2 u_p^2 / 2(m + m_0),$$

where m_0 is the mass of the deformed surface elemnet. One can see that for no deformation ($m_0 = 0$) or for small deformation ($m_0 << m$), this energy can be accepted in the primary form as derived by the author.

As it follows from the discussions and the results given in (8) and (9), the second critical velocity, above which the particle adhesion increases, and attributed by the authors of (8) to the deformation at the collision, is very large as compared to the velocities used for the phase separation in the dispersed systems. According to the experimental results in (8) the deformation takes place for the decreasing particle sizes at decreasing velocities, starting for the particles of the order 1 - 2 μm at several m/sec for the collisions with paraffin. In the case of solid materials, for which the hardness exceeds several times the hardness of paraffin (6), these velocities will be much higher, they reach several hundred m/sec (8). On the other hand, if the colliding surface is the liquid, the mechanical deformation can be only temporary, and the contact surface and at the same time the contact coefficient, is

determined by the meniscus height on the particle which is dependent on the liquid wetting angle.

The use of the velocities less than a few m/sec in the phase separation process, is due to the fact that the higher velocities would require higher energies to overcome the hydraulic resistance, which is connected with the problem economics, and also because at the higher velocities the particle separation would take place, and thus the decrease in process efficiency. One has to point out that the very small particles, smaller than 1 μm also completely adhere due to the causes other than the deformation, namely due to the high values of the specific adhesion energy A, which is proportional to $1/r^2$ (r - the particle radius). In other words, the particles could in general undergo the complete adhesion even without the deformation. The diffficulties in separation of such particles (5) are caused by the difficulty in the collision itself with the streamlined obstacle due to the inertia, trapping or gravitation, and the diffusion takes place for the particles smaller than 0.3 - 0.5 μm. From the experiments and discussions in (8) and (9) it follows that the increase of velocity to above the second critical velocity should increase the effectiveness of the separation process, especially because with the increase of velocity the effectiveness of inertial collisions also increases. It applies only to the particle collisions with the given surface, that is to the covering mono-layer. However, in the practically applied phase separation processes, the surface coating is multilayered, therefore, after the short time the collision surface becomes structurally the particle layer. In this case the specific adhesion energy, which for the mutual particle adhesion in the layer is called the specific autoadhesion energy, is considerably reduced as compared with the adhesion to the solid state surface (10). The exception are the collisions of wettable

particles with the fluid, that is, the particles for which the wetting angle with the given fluid is less than 90° (11), and which are wetted by the fluid after the collision.

It follows then from these remarks, that it is justified to neglect the deformation phenomenon in the models used for the determination of the adhesion criterion of the particles to the collision surface in phase separation processes, and this does not introduce any essential discrepencies.

2. Derivation of the Adhesion Criterion of Particles to the Collision Surface for the Case of Rebound

This problem will be studied under the assumption of ideal elastic collision without the sliding. Ignoring the sliding is justified in this case, since if at the lack of rebound the adhesion force is by assumption so strong, that it does not allow for the particle motion, there should not be any sliding at the collision but at the most the rebound. In the instant of collision, however, the adhesion force is acting and if it is comparable with the particle impact force, it brakes the particle. This is why the term "quasi-elastic rebound" is used. The adhesion force is the factor causing certain "nonelasticity", and it is relatively large for the particles of the order of several tens of μm (10). When the particle collides with the stationary surface, this phenomenon can be considered as a collision with the wall, and if the colliding surface element moves with the velocity v, that phenomenon can be similarly treated. We are not interested in the direction of motion of the obstruction element, or in the change of its kinetic energy, so in this case the relative velocity between the particle and the surface element should be used for the collision velocity.

Fig 1a. shows the distribution of forces during the elastic collision, ignoring the adhesion force. The impact force is distributed into normal force F_N, which gives the reaction force - F_N, and the tangential force F_s. The resultant force F of F_N and F_s forms the angle with the normal direction which equal to the collision angle γ, and is equal in size to φ the collision force F_z.

In Fig 1b. the distribution of forces is shown when the adhesion force F_A is taken into account (quasi-elastic collision). In this case $\gamma < \varphi$ and $F < F_z$. For the case of $F_A \geq | - F_N |$, due to the fact that the adhesion force has no reaction, $F_N = 0$ and the particle will not rebound but will remain at the surface, along which it may move.

In the case of quasi elastic particle rebound, it is natural to adopt as the adhesion or separation criterion, the ratio F_A / F_N or E_A / E_N, where E_A is the adhesion energy corresponding to the force F_A, and E_N - the reaction energy corresponding to the force F_N. Therefore

$$U_p^* = \frac{E_A}{E_N}. \qquad (8)$$

Since $E_A = AS_r$, $E_N = E_z \cos\varphi$ (Fig. 1), and $E_z = mu_p^2/2$, then from the analogous consideration one obtains:

$$U_p^* = \psi_1 \frac{A}{mu_p^2 \varrho_1 \sqrt{1-\beta_c}}, \qquad (9)$$

where $\psi_1 = 12\xi_0 / \cos\varphi\sqrt{f}$.

Making the previous assumption (1) $u_p = C_n \frac{u}{R}$ and introducing the hydrodynamic factor H^*, according to the expression (4), one obtains :

$$U_p^* = 4H^{*2}\psi_1 \frac{A}{mu_0^2 \varrho_1 \sqrt{1-\beta_c}}, \qquad (10)$$

where $\psi_p = 12\xi_o / C_o^2\sqrt{f\infty} \cdot \cos\varphi$. This criterion is analogous to the one obtained in (1) and given in expression (7).

In criterion (10) there is no static friction coefficient μ_o, but there is the cosine of the incident angle, value of which is different for different stream lines. The angle φ can be averaged, but because of the unknown values for ξ_o and C_o, which are certain types of average values, the quality ψ_p has to be treated in practice as an empirical constant, and the averaging of the angle φ is not useful.

If there is no rebound, but there is some translational movement of the particle, then the criterion (10) changes into criterion (7) by replacing ψ_p by ψ_p'' and reverse.

3. Problem of the Particle Rolling on the Collision Surface.

The adhesion criterion in work (1) were derived as if the particle moved along the collision surface in translational motion (taking into account the static friction coefficient μ_o). But in many cases the particle rolling is possible and quite probable. This is due to both the particle shape and their velocity distribution along the particle surface which causes their angular momentum. One can show that for the case of particle rolling, the considerations lead to the similar type of criteria as derived in (1) and cited in this work. For the rolling (without the slip, and about the center of the mass) the reaction energy is equal to

$$E_r = mu_p^2/2 = mu_{pl}^2(2 + I\omega^2)2,$$

where I is the particle moment of inertia, ω - the angular velocity, u_{pl} - the translational velocity. Using $w = u_{pl} / r$, and $I = k_o\, mr^2$ where r is the particle size corresponding to its effective radius, k_o - the numerical coefficient of the moment of inertia, and considering (1) for

the turbulent flow (instabilities of the boundary layer, vortices or stream mixing) $\mu_{pl} = k_1 \mu$, one obtaines the analogous expression for the reaction energy

$$E_r = [k_1^2(1 + k_0)/2]mw^2 \quad \text{or} \quad E_r = (k/2)mw^2,$$

where $k_1^2(1-k_0)=k$.

The value of the coefficient k_0 depends on the particle shape and if it is "hollow" or solid, thus to a certain degree on its porosity. For example, for a sphere k_0 = 2/5, for the solid sphere of the radius r_1, the moment of inertia I = (2/5) m r_1^2, and for the hollow sphere with the outside radius r_1, and inside radius r_2 the moment of inertia is :

$$I = (2/5)m(r_1^5 - r_2^5)/(r_1^3 - r_2^3).$$

For the solid cylinder of radius r_1 the moment of inertia about its axis is I = (½) m r_1^2, and for the hollow cylinder with the outside radius r_1 and inside radius r_2 it is equal to

$$I = (1/2)m(r_1^2 + r_2^2),$$

thus k_0 = ½.

If we adopt the hollow body model for the porous particles, with the equivalent shape of sphere or cylinder with the diameter equal to its height, that is the model in which all the pores are lumped into one equivalent volume with the radius r_2, then the given moments of inertia can be expressed as functions of the outside diameter r_1 and the particle porosity. Since in this case for the hollow sphere $\beta = r_2^3 / r_1^3$ and for the hollow

cylinder $\beta_c = r_2^2 / r_1^2$, then using $2 r_1 = a_k$ where a_k is the kinetic particle size as explained above, one obtains for the hollow sphere

$$I = 0{,}1\, m a_k^2 (1 - \beta_c^{5/2}) / (1 - \beta_c),$$

and for the hollow cylinder

$$I = (1/8) m a_k^2 (1 - \beta_c),$$

For the solid sphere $I = 0.1\, m a_k^2$, and for the solid cylinder $I = (1/8)\, m a_k^2$.

In these relations one can replace the kinetic values a_k with the dynamic values a using the relation from work (2) as given here. But the model would be far from the reality. It appears that it would be more correct to adopt the model of rolling porous particle as a body with the uniformly distributed mass with a density equal to the apparent density ρ_k, expressed as the ratio of the mass to the kinetic volume, that is the volume of the particle material and the pores. In such a case ($r_1 = r = a_k / 2$) one can write in general

$$I = 0{,}25\, k_0 (1 - \beta_c)\, m a_k^2,$$

and as previously, one obtains

$$M_r = \{k_1^2 [1 + k_0 (1 - \beta_c)]\}\, m w^2.$$

The adhesion energy in the case of rolling is

$$W_\mu = \mu_1 \Delta N_r / r = 2 \mu_1 \Delta N_r / a_k,$$

where μ_1 is the rolling friction coefficient, which has the dimension of length. After the similar operations, one obtains the following adhesion criterion for the rolling particle in the turbulent flow

$$U_p^* = \psi_{11} \frac{A}{[1 + k_0(1-\beta_c)]a_k a w^2 \varrho_f \sqrt{1-\beta_c}}, \qquad (11)$$

where $\psi_{11} = 12\mu_1 \xi_0 / k_1^2 \sqrt{f}$.

Substitiuting the near flow velocity u with the flow velocity away from the onstruction u_0 using the expression (4), and the kinetic particle dimension a_k with a dynamic dimension a, one obtains

$$U_p^* = 4H^{*2}\psi_1'' \frac{A}{a^2 u_0^2 \varrho_f [1 + k_0(1-\beta_c)]}, \qquad (12)$$

where $\psi_1'' = 12\mu_1 \xi_0 / f k_1^2$.

In the case of laminar and static boundary layer, given in study 1, and assuming the translational particle motion, the adhesion criterion including the hydrodynamic factor is (4) :

$$U_p^* = 8H^{*3}\psi_p' \frac{\mu h A}{a^2 u_0^2 \varrho_f \varrho \sqrt{1-\beta_c}}, \qquad (13)$$

where $\psi_p' = 1.8\,\mu_0 \xi_0$, μ- dynamic fluid viscosity, h - stream length, ρ - fluid density. Similarly, for the rolling particle one obtains

$$U_p^* = 8H^{*3}\psi_t' \frac{\mu h A}{a^4 u_0^2 \varrho_f \varrho [1 + k_0(1-\beta_c)]}, \qquad (14)$$

where $\psi_t' = 1.8\,\mu_1 \xi_0 / f k_1^2$.

The value of coefficient k_0 depends on the equivalent particle shape assumption. For the sphere $k_0 = 2/5$ and the cylinder $k_0 = \frac{1}{2}$.

According to the adopted model, these relations apply to the porous particles, assuming that the pores are uniformly distributed in the particle volume. Nonuniformity in pores distribution lowers the model accuracy,

In practice, especially in the phase separation devices, the flow is generally with the turbulent boundary layer. Therefore, the main application will have the criterion (7) (for the translational motion) and (12) (the rolling motion). For the case of particle rebound only the criterion (10) can be applied.

4. Application of the Derived Criterion

For the single particle the following relation holds : if $G^*_p < 1$, then the rebound takes place or the particle translation, however if $G^*_p \geq 1$ there is no rebound or particle translation.

For the particle assembly, if the adhesion probability after the collision is denoted by

$$\lambda_p = \frac{N_p}{N_z}, \qquad (15)$$

where N_p - the number of particles remaining on the surface after N_z particles collided with it number of colliding particles. If we introduce the normalizing factor δ_{Np}, and use the relation

$$N_p / N_z = \delta_{Np}\, \varphi(G^*_p)$$

one can write (1, 2) :

$$\lambda_p = \begin{cases} \delta_{Np}\varphi(G^*_p) & \text{dla } \delta_{Np}\varphi(G^*_p) < 1, \\ 1 & \text{dla } \delta_{Np}\varphi(G^*_p) \geq 1. \end{cases} \qquad (16)$$

The more detailed discussion on application of λ and G^*_p in the theory

of phase separation of the dispersed system are given in (12).

OZNACZENIA – SYMBOLS

A	– energia właściwa adhezji (energia przypadająca na jednostkę powierzchni styku), specific adhesion energy (energy corresponding to a unit surface area of contact)	J/m^2
a	– dynamiczny wymiar cząstki (wymiar cząstki będący funkcją jej prędkości opadania w płynie lepkim według określonego prawa ruchu, np. prawa Stokesa) dynamic particle dimension (particle dimension being a function of particle terminal velocity in a viscous fluid according to the determined law of motion, for example Stokes'law)	
a_k	– geometryczny kinetyczny wymiar cząstki (wymiar charakteryzujący kinetyczną, czyli obwiednią powierzchnię cząstki o dowolnym kształcie i porowatości) geometric kinetic particle dimension (dimension characterising a kinetic, i.e. an enveloping particle surface of any shape or porosity)	m
a_v	– geometryczny statyczny objętościowy wymiar cząstki (wymiar cząstki charakteryzujący objętość materiału cząstki o dowolnym kształcie i porowatości, bez objętości jej ew. porów) geometric static volumetric particle dimension (particle dimension characterizing volume of particle solid of any shape or porosity, without its porous volume)	m
O	– stała Happela-Kuwabary Happel-Kuwabara constant	

c_0 – współczynnik proporcjonalności
proportionality coefficient

E_A – energia adhezji cząstki do powierzchni zderzenia [J]
energy of particle adhesion to collision surface

E_N – energia reakcji pochodząca od siły normalnej (energia odbicia cząstki) [J]
reaction energy resulting from normal force (energy of particle rebound)

E_p – energia przyczepności cząstki do powierzchni zderzenia [J]
energy of particle adhesion to collision surface

E_r – energia reakcji dążąca do oderwania cząstki po zderzeniu [J]
reaction energy acting towards particle detachment after collision

F – wypadkowa siły normalnej i stycznej [N]
resultant force of normal and tangential force

F_N – siła normalna przy zderzeniu cząstki z powierzchnią zderzenia [N]
normal force at particle collision with colliding surface

F_s – siła styczna przy zderzeniu cząstki z powierzchnią zderzenia [N]
tangential force at particle collision with colliding surface

f – współczynnik ruchu
coefficient of motion

G_p^* – kryterium przyczepności (odrywu) cząstki od powierzchni zderzenia
criterion of particle attachement (detachment) to colliding surface

h – długość drogi opływu powierzchni zderzenia przez płyn (fazę rozpraszającą) [m]
distance of fluid flow at colliding surface

H^* – czynnik hydrodynamiczny (charakteryzujący pole prędkości przy opływie)
hydrodynamic factor (characterizing the velocity field of flow)

I – moment bezwładności toczącej się cząstki [kg·m²]
inertial momentum of rolling particle

k_0 – liczbowy współczynnik momentu bezwładności cząstki
coefficient of inertial momentum of particle

k_1 – współczynnik proporcjonalności
proportionality coefficient

m – masa cząstki [kg]
mass of particle

N_p – liczba cząstek pozostających na powierzchni po zderzeniu się z nią liczby cząstek N_s
number of particles remaining at surface after collision of N_s particles

N_s – liczba cząstek zderzających się z daną powierzchnią
number of particles colliding with surface

r – promień cząstki kulistej lub cylindrycznej, lub zastępczy promień cząstki (promień cząstki o zastępczym kształcie kulistym lub cylindrycznym) [m]
radius of spherical or cylindrical particle, or equivalent particle radius (particle radius for equivalent spherical or cylindrical shape)

Re – liczba Reynoldsa odniesiona do wymiaru (średnicy) opływanego elementu
Reynolds number referred to dimension (diameter) of element flown around

S_k –

S_r –

u –

u_0 –

u_p –

u_{pl} –

v_f –

w –

β –

β_0 –

β_k –

γ –

δ_{Np}

λ_p

S_k – kinetyczna (obwiednia) powierzchnia cząstki o dowolnym kształcie i porowatości
kinetic (envelope) particle surface with any shape or porosity — m^2

S_r – rzeczywista pole powierzchni styku cząstki z powierzchnią zderzenia
real surface area of particle contact with colliding surface — m^2

u – prędkość płynu w pobliżu opływanej powierzchni zderzenia
velocity of fluid at colliding surface flown around — m/s

u_0 – prędkość płynu w dalekiej odległości od opływanej powierzchni
velocity of fluid at far distance from surface flown around — m/s

u_p – średnia prędkości cząstki na odległości a_k od powierzchni zderzenia (prędkość z jaką cząstka przemieszczałaby się pod wpływem opływającego powierzchnię płynu przy przewadze energii płynu nad energią przyczepności)
average particle velocity at distance a_k from colliding surface (velocity of particle motion under influence of fluid flowing around surface at superior fluid energy in comparison with adhesion energy) — m/s

u_{pt} – prędkość postępowego ruchu toczącej się cząstki
progressive motion velocity of rolling particle — m/s

v_f – statyczna objętość cząstki o dowolnym kształcie i porowatości (objętość materiału cząstki, z wykluczeniem objętości ewentualnych porów)
static volume of particle of with any shape and porosity (volume of particle material without porous volume) — m^3

w – prędkość dopływu płynu do systemu ciała porowatego
velocity of fluid flow to porous system — m/s

β – stopień upakowania systemu ciała porowatego
degree of porous system compactness

β_c – porowatość cząstki (stosunek objętości porów cząstki do jej objętości kinetycznej, tzn. objętości ograniczonej kinetyczną czyli obwiednią powierzchnią cząstki; objętość ta jest odpowiednikiem pozornej objętości warstwy porowatej lub ciała porowatego)
particle porosity (ratio of particle porous volume to its kinetic volume, i.e. volume limited by kinetic enveloping particle surface; this volume is equivalent to quasi-volume of porous layer or porous solid)

β_k – kinetyczna porowatość systemu (ciała) porowatego, tzn. stosunek objętości porów między elementami systemu porowatego (bez uwzględnienia porów wewnątrz samych elementów) do objętości danego systemu, np. warstwy nasypowej, materiału włóknistego itd.
kinetic porosity of porous system (solid), i.e. the ratio of porous volume between the elements of the porous system (without pores inside elements) to the system volume, for example: bank layer, fibrous material etc.

γ – kąt odbicia cząstki od powierzchni zderzenia
angle of particle rebound from colliding surface — deg

δ_{Np} – czynnik normujący
normalizing factor

λ_p – prawdopodobieństwo przyczepienia cząstki do powierzchni zderzenia
probability of particle attachment to colliding surface

μ	– dynamiczna lepkość płynu dynamic viscosity of fluid	kg/m·s
μ_0	– współczynnik tarcia statycznego między powierzchnią cząstki i powierzchnią zderzenia coefficient of static friction between particle surface and colliding surface	
μ_t	– współczynnik tarcia tocznego między powierzchnią zderzenia, a toczącą się po niej cząstką coefficient of rolling friction between colliding surface and rolling particle	m
ξ_0	– współczynnik styku contact coefficient	
ϱ	– gęstość płynu fluid density	kg/m³
ϱ_f	– bezwzględna (materiałowa) gęstość cząstki absolute (solid) particle density	kg/m³
φ	– kąt zderzenia (padania) cząstki z powierzchnią zderzenia angle of collision (fall) of particle with colliding surface	deg
ψ_s	– współczynnik zastępczego kształtu kinetycznej (obwiedniej) powierzchni cząstki coefficient of equivalent shape of kinetic particle surface	
ψ_v	– współczynnik zastępczego kształtu statycznej objętości cząstki coefficient of equivalent shape fo static particle volume	
ω	– prędkość kątowa toczącej się cząstki angular velocity of rolling particle	1/s

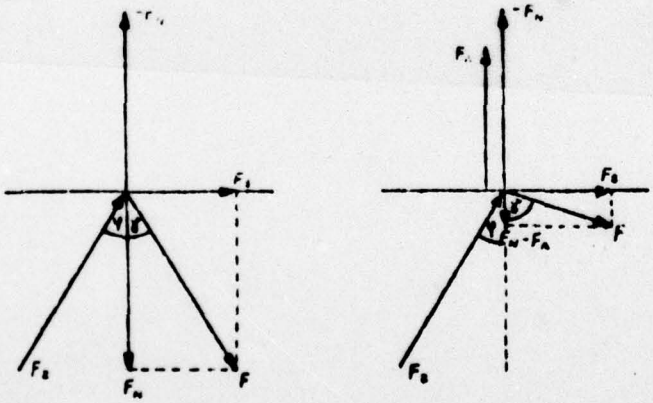

Fig. 1. Distribution of forces in elastic slippless collision of a solid (a particle) with a surface if neglect adhesion force (a) and taking it into account (b) when momentum change of colliding surface is equal 0

Bibliography

[1] W. Gutowski, Inż. Chem., III, 3, 477 (1973).

[2] W. Gutowski,

Materials of the international symposium of the COMECON states:

Fibrous and woven filters - theory, methods of study, application p. 39.

Institute of Fundamentals of Environmental Engineering, Polish Academy of Sciences in Zabrze, Wisla, November 3 - 6, 1975.

[3] C. N. Davies, *Air Filtration*, Academic Press, London – New York 1973.
[4] N. A. Fuks, I. B. Stechkina, Ann. Occup. Hyg., 6, 1, 27 (1963).
[5] N. A. Fuks, *Mjechanika aerozoljej*, AN ZSRR, Moskwa 1955.
[6] W. I. Skitowicz, B. I. Ogorodnikow, I. W. Petrjanow, jak pos. [2], s. 74.
[7] B. F. Sadowskij, G. I. Barjerkina, G. A. Czjernjajewa, jak pos. [2], s. 103.
[8] A. D. Zimon, K. A. Łazarjew, Kolloidnyj Żurnal, XXXI, 2, 214 (1969).
[9] A. D. Zimon, K. A. Łazarjew, Kolloidnyj Żurnal, XXXI, 1, 59 (1969).
[10] A. D. Zimon, *Adgezja pyli i porosżkow*, Izd. Chimija, Moskwa 1967.
[11] W. Gutowski, Staub-Reinhalt. Luft, 35, 7, 266 (1975).
[12] W. Gutowski, Inż. chem., VII, 1, 51 (1977).

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